The extended X-ray emission around HDF 130 at z=1.99: An inverse Compton ghost of a giant radio source in the Chandra Deep Field North

Reference
A.C. Fabian, S. Chapman, C.M. Casey, F. Bauer and K.M. Blundell
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Wu, Ei-Han
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News

• This is the first detection of such a high-energy apparition.

• It is evidence of a huge eruption produced by the supermassive black hole.

• A valuable opportunity to observe phenomena that occurred when the Universe was very young.
HDF130: Ghost Remains After Black Hole Eruption

Credit: X-ray (NASA/CXC/IoA/A.Fabian et al.); Optical (SDSS), Radio (STFC/JBO/MERLIN)
Fast Facts for HDF 130:

Scale: Image is 8.2 arcmin across
 Coordinates (J2000):
   RA-> 12h 36m 17.6s
   Dec-> +62° 15' 44.5"

Constellation: Ursa Major
 Observation Date: 11/20/2000-02/22/2002

Distance Estimate: About 10 billion light years
 Release Date: May 28, 2009
1 INTRODUCTION

The deepest published X-ray image of the Chandra Deep Field North (CDFN: Alex 2002) studied the 6 extended sources of this field and inferred their sizes and groups. Casey et al. (2008) have described the HDF 130, at the centre of one of these CDFN J123620.0+621554, of Bauer et al. (2002), is a massive elliptical galaxy at redshift $z = 1.99$, and not a starburst galaxy as earlier supposed. HST/NICMOS and Spitzer/IRAC imaging have revealed that the object has a massive ($\sim 3 \times 10^{12} M_\odot$) old stellar population with a large diameter of about 8 kpc. It is intrinsically weak at submillimetre wavelengths and has a compact radio source, indicative of a central Active Galactic Nucleus (AGN). We investigate here the possibility that the double-lobed structure of the extended X-ray source is not then due to a surrounding merging cluster, as suggested by Bauer et al. (2002), but instead to inverse Compton (IC) emission from a past outburst of the galaxy. The object would in the past have appeared as a giant radio galaxy, but inverse Compton

ABSTRACT

One of the six extended X-ray sources found in the Chandra Deep Field North is centred on HDF 130, which has recently been shown to be a massive galaxy at $z = 1.99$ with a compact radio nucleus. The X-ray source has a roughly double-lobed structure with each lobe about 41 arcsec long, or 345 kpc at the redshift of HDF 130. We have analyzed the 2 Ms X-ray image and spectrum of the source and find that it is well fit by a power-law continuum of photon index 2.65 and has a $2-10$ keV luminosity of $5.4 \times 10^{43}$ erg s$^{-1}$ (at $z = 1.99$). Any further extended emission within a radius of 60 arcsec has a luminosity less than half this value, which is consistent with what is expected from a cluster of galaxies. The source is best explained as an inverse Compton ghost of a giant radio source, which is no longer being powered, and for which Compton losses have downgraded the energetic electrons, $\gamma > 10^4$, required for high-frequency radio emission. The lower energy electrons, $\gamma < 1000$, produce X-rays by inverse Compton scattering on the Cosmic Microwave Background. Depending on the magnetic field strength, some low frequency radio emission may remain. Further inverse Compton ghosts may exist in the Chandra deep fields and beyond.

Key words: X-rays: galaxies — galaxies: clusters — intergalactic medium — galaxies: individual (RG H13617)

Fabian et al. (2003), 6C 0905+39 ($z = 1.833$, Blundell et al. 2006; Erlund et al. 2008) and 4C 23.56 ($z = 2.48$, Johnson et al. 2007). The flux of the emission depends on the energy density of the target photons, which in case of the CMB rises as $(1+z)^4$ so cancelling out the dimming expected from increased distance (Felten & Rees 1969; Schwartz 2002). In the case of 3C 294 there are distinct large patches of X-ray emission separate from the observed radio source (Erlund et al. 2006) and in 6C 0905+39 most of the X-ray emission lies in between the hotspots where no radio emission is seen (Erlund et al. 2008). The lifetime of the electrons in the sources scales as $1/\gamma$ due to radiative losses. Lorentz factors of $\gamma \sim 1000$ are required to upscatter the CMB photons and $\gamma \sim 10^4$ (depending on the magnetic field strength) to generate GHz synchrotron radiation in the radio band. Consequently when the AGN switches off and no further electron acceleration takes place, the
Figure 1. X-ray image of the source in the 0.3–3 keV band. The data have been binned into 1 arcsec pixels and gaussian smoothed by 5 pixels. 20 arcsec is indicated by the bar on the left and the position of the massive galaxy HDF 130 hosting the (unresolved) radio source of Casey et al (2008) is marked by a cross.
Conclusions

This could mean that the radio source is only detectable at low radio frequencies (few 100 MHz) and thus, for example, with the giant metrewave radio telescope (GMRT) or in the future with Low Frequency Array (LOFAR) and similar instruments.

Bauer et al (2002) note that there may be about 150 extended X-ray sources per square degree. If even 10 per cent of them are similar to the HDF 130 source then they have a space density of roughly $10^{-6}$ Mpc$^{-3}$ ($3 \times 10^{-8}$ Mpc$^{-3}$ in comoving units), close to the estimate of Celotti & Fabian (2004) for sources of luminosity $\sim 10^{44}$ erg s$^{-1}$. The Compton cooling time at $z = 2$ is about 30 Myr, whereas the time from $z = 2.5$ to 1.5 is about 1.7 Gyr. Therefore the space density of objects giving rise to ghosts (assuming they each only undergo one jet-active phase) is 50 times the above value or $\sim 10^{-6}$ Mpc$^{-3}$ in comoving units, comparable to the number density of massive galaxies ($M_K < 25$; Cole et al 2001). It is even higher if expansion losses dominate, as expected.

A direct demonstration of our IC explanation for the extended X-ray emission around HDF130 would be the clear detection and mapping of the radio source itself at low radio frequencies (e.g. 100 MHz), where the Compton losses are less and the emitting electrons closer in energy to the X-ray ones.

We conclude that the X-ray Sky may be littered with faint inverse Compton ghosts.
Thank you